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Condition and Type of Housing as an Indicator of Potential Environmental Lead Exposure and Pediatric Blood Lead Levels[1]

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Environmental evaluations in a prospective behavioral study of children with blood lead levels up to about 50 μg/dl were performed by an intensive environmental survey and by exterior visual evaluation of housing quality. Serial blood lead values for infants in the study were compared to exterior housing type and quality, which itself was also compared with results of the intensive environmental evaluation. Five housing condition and type categories were defined: public housing; private housing (satisfactory, deteriorated, and dilapidated); and rehabilitated private housing. In this interim report on the first subset of available data, the housing categories were found to differ in paint and environment dust lead levels, with public and rehabilitated housing having lowest values. Blood lead concentrations of children differed across housing categories as early as 6 months of age, with children residing in public housing having lowest levels, followed by those in rehabilitated housing. The spread in mean blood lead concentrations among the housing quality categories increased with increasing age of the children. Housing category accounted for over one-half of the blood lead variability in 18-month-old children. © 1985 Academic Press, Inc.

INTRODUCTION

Lead-based paint in older houses has long been associated with elevated blood lead in children residing within them. The causal relationships were earlier thought to be mainly due to the ingestion of lead-based paint chips (Lin-Fu, 1967). More recently it has been suggested that the intake of house dust contaminated with lead is a significant pathway for at least part of the increased burden of lead in children with moderately elevated levels of lead (Charney *et al.*, 1980). There has been considerable debate concerning whether the source of lead in the dust comes from painted surfaces or from automotive or industrial air pollution fallout. The source of the lead certainly depends on the characteristics of the community. Children living in dilapidated housing have been found to have elevated blood lead as early as 7–10 months of age (Bradley *et al.*, 1956). Even in situations where housing was thought to be the primary source of the lead, few data are available that directly address the question of the age at which the influence of housing commenced.

Sources of lead in the environments of children in the Cincinnati prospective

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study are determined periodically by an intensive on-site survey that focuses on the measurement of interior and exterior paint lead and a variety of dust samples: surface dust and dust fall (interior and exterior), handwipes, and soil. The high rate of moving by families from one dwelling unit to another, however, results in a large portion of the dwellings not being subjected to the intensive environmental evaluation. On average there was more than one housing relocation per subject per year. In order to partially compensate for the resulting lack of environmental information, an exterior or "windshield" survey procedure to assess building type and condition was developed. This procedure was based on assumptions regarding lead availability, condition, and age of house. Windshield surveys have often been used in the past to assess rapidly certain characteristics of housing primarily related to level of maintenance. We were aided in the development of the exterior evaluation procedure by our previous lead source studies in a variety of neighborhoods throughout the Cincinnati area (Reece *et al.*, 1972; Bertinuson *et al.*, 1973; Clark *et al.*, 1974; Hammond *et al.*, 1980) and by participation in community housing development activities in Cincinnati over two decades.

In Cincinnati, housing can be classified into three general types: public housing, nonrehabilitated private housing, and rehabilitated private housing. Public housing has been constructed by the local public housing authority since the mid-1930s under U.S. public housing statutes. This type of housing is subsidized and intended for low and moderate income families. Since it is relatively new housing, it generally contains low-lead paint. Typically this public housing was constructed in clusters of 100 or more dwelling units, and a large portion of the building lot was devoted to open space, frequently green. It is possible to identify readily by exterior observation whether housing is "public housing" or whether it has been "rehabilitated" as subsidized housing.

Most of the private housing stock in which our cohort resides was built in the 19th century or in pre-World War II 20th century and usually contains multiple sources of high-lead paint. Some of the private housing, however, was built after World War II in which case low-lead or lead-free paint was almost always used. This newer housing was constructed on lots where a large portion of the land was devoted to parking and to green space, similar to the practice for public housing.

Rehabilitated housing refers to older housing in Cincinnati that was extensively rehabilitated by private nonprofit and for-profit developers under 1965 and later U.S. housing laws. These older, predominantly 19th century houses usually contained high-lead paint prior to rehabilitation. This housing is also subsidized and is intended for low- and moderate-income families. The interiors of these rehabilitated houses were frequently "gutted." Virtually all surfaces on the interior of this rehabilitated housing are therefore new, and low-lead or "lead-free" paint was used in them. Exteriors were either sandblasted or chemically cleaned, thereby dispersing exterior leaded paint to the ambient environment. The older houses from which these rehabilitated units were derived frequently occupied very high proportions of the lots on which they were built, with any available land outside the houses frequently being paved. This lack of exterior space adjacent to the house generally persisted after the rehabilitation process. Often the housing adjacent to the rehabilitated housing was not rehabilitated and frequently was in poor condition. The rehabilitated housing itself was therefore virtually lead free, but it frequently existed in close proximity, often sharing a common wall, with houses containing abundant sources of lead. The subsidized rehabilitated housing discussed in this paper should not be confused with renovations of older houses by middle- and upper-income families, a common practice in Cincinnati and elsewhere. The latter renovated houses often include interior woodwork from which the lead has been removed by chemical or heat methods. In the subsidized rehabilitated houses, older woodwork was almost always replaced by standard grade new lumber, and all rehabilitation work was performed while the buildings were unoccupied. The middle- and upper-income housing is not within the financial means of the families of the study subjects.

Housing conditions were assessed as satisfactory, deteriorated, and dilapidated. The first condition was used for housing which, from the outside, appeared to be well maintained and had no peeling paint visible from the street. Deteriorated housing was missing one or both of the above features. Dilapidated housing was judged to be similar to deteriorated housing except that the lack of maintenance also resulted in structural defects such as missing trim, broken windows or doors. Since the use of lead-based paint in the public, rehabilitated, and newer private housing is rare, the condition factor was not judged to be as important as when applied to housing where there was a priori reason to believe that high-lead paint was likely to be present and was therefore not applied to them for the purpose of this paper.

Sources of lead other than paint such as in water and air exist to a degree in Cincinnati as they do elsewhere. The water supply was the same for all of the population in our study, and its primary source is the Ohio River. The water supply is highly buffered with a pH of about 7.7 (Miller, 1984) and has a low plumbosolvency for any lead pipe or fixtures that may exist in the housing. Monthly grab samples of tapwater from throughout the Cincinnati Water Works distribution system during 1981–1984 contained a median lead concentration that was below the detection limit of 5 ppb, and the highest value found was 6.0 ppb (Young, 1985).

Air lead in Cincinnati is generally in the range 0.2–1.0 $\mu g/m^3$. A large portion of the public housing is located within 500 m downwind of the major north–south interstate highway system in Cincinnati, and some is as close as 100 m. There has been a steady decline in average air lead concentrations in the study area over the last 10 years with the current average concentration being 0.3 $\mu g/m^3$.

In this interim report, the results of the intensive environmental evaluations and blood lead analyses were each compared to housing quality/housing type as described above.

METHODS

Study participants were part of the ongoing Cincinnati prospective study, details of which have been presented elsewhere (Bornschein *et al.*, 1985).

Blood samples were obtained by venipuncture at 3-month intervals with the first sample being collected at an age of 10 days. Blood lead analyses were performed using a cold digestion anodic stripping voltammetric method (Morrell *et al.*, 1976). Families of study participants frequently changed residences. If the child did not change homes from birth through the period of time under consideration or moved between buildings in the same housing quality category, the entire record of blood lead data was utilized. However, if the move was between housing in different categories, only the blood lead data from birth up until the time of the move was utilized in this evaluation. All laboratory analyses of paint, dust, and soil samples were performed using atomic absorption spectrophotometry (AAS) by a laboratory accredited in industrial hygiene chemical analyses. Surface paint lead concentrations (mg Pb/cm^2) were detected by use of a 0.122 MeV Co^{57} portable X-ray fluorescence (XRF) analyzer. Methods for collecting and analyzing the dust and soil samples are described in detail elsewhere (Que Hee *et al.*, 1985). These methods included surface dust collection with a stainless-steel sampler and a vacuum pump (2 liters/min) using three passes over a measured area usually 22 × 22 cm. Three wipes were performed for collection of hand dust. Three digestions/decantations were done for dust and paint samples and one for handwipes. Dustfall was obtained using the polyethylene containers described by Angle *et al.* (1979).

Housing quality was assessed by the drive-by exterior evaluation previously described. Buildings containing the dwelling units of the study participants were assigned to one of five quality categories:

I. Public housing and post-World War II housing constructed privately.
II. Rehabilitated housing.
III. Pre-World War II housing—satisfactory appearance.
IV. Pre-World War II housing—deteriorated appearance.
V. Pre-World War II housing—dilapidated appearance.

The deteriorated and dilapidated categories for pre-World War II housing were combined in the comparisons with blood lead of occupants because of the small number of children residing in dilapidated housing.

RESULTS

Results of analyses to date of environmental samples, categorized according to exterior housing quality, are presented in Table 1. As expected the lead content, as determined by XRF, in public and rehabilitated housing is very low compared to that of the older private housing. Similarly, the lead content of interior surface dust (PbD), expressed in terms of either an area (mg Pb/m^2) or concentration ($\mu g/g$), is lowest for the public and rehabilitated housing and highest for the older private housing in deteriorated or dilapidated condition. Lead in interior dust fall (PbD fall, mg Pb/m^2/30 days) did not vary as much between the housing categories (factor of 10) as did the lead in PbD (mg/m^2) which showed 16-fold differences but was still lower in the public and rehabilitated housing than in the other categories. Mean interior dustfall (mg Pb/m^2/30 days) in public housing was only about one-fifth that of rehabilitated housing. Although relatively few exterior dust scrapings have been analyzed, concentrations appeared to be lowest for public housing. Only a six-fold variation in the amount of hand lead existed between

TABLE 1

ENVIRONMENTAL LEAD LEVELS ASSOCIATED WITH HOUSING QUALITY CATEGORY

Total	Public I	Rehabilitated II	Private nonrehabilitated: Satisfactory III	Private nonrehabilitated: Deteriorating IV	Private nonrehabilitated: Dilapidated V
XRF[a] (mg/cm²)					
Geom. mean	1.2	1.0	10.0	11.7	14.5
Range	0.6–2.3	0.1–15.2	0.3–21	0.1–35	0.8–29
N = 175	13	40	34	59	29
PbD[b] (mg/m²)					
Geom. mean	0.20	0.37	0.75	3.0	3.2
Range	0.04–1.2	0.06–11.3	0.1–21	0.1–30	0.2–39
N = 143	12	45	30	39	17
PbD[b] (μg/g)					
Geom. mean	350	623	1410	2200	3000
Range	192–1160	72–5200	390–7000	305–16,200	360–9100
N = 153	12	46	33	45	17
PbD fall[c] (mg Pb/m²/30 days)					
Geom. mean	0.025	0.116	0.152	0.22	0.21
Range	0.0100–0.055	0.0006–0.53	0.0006–1.0	0.0006–60	0.0040–2.5
N = 130	9	39	24	45	13
PbED[d] (μg/g)					
Geom. mean	340	2,000	5,000	6,000	15,700
Range	20–1070	167–11,000	2300–23,000	120–108,000	610–62,000
N = 85	5	27	8	35	10
PbH[e] (μg)					
Geom. mean	3.0	7.0	8.0	10.5	12.0
Range	1–29	1–86	1–27	1–191	1–105
N = 136	9	40	24	46	17

[a] XRF = geometric mean of maximum (mg/cm²).
[b] PbD = geometric mean of the median interior surface dust by vacuum collection.
[c] PbD fall = geometric mean interior dustfall.
[d] PbED = geometric mean of the median exterior dust scraping.
[e] PbH = geometric mean of handwipes of subjects.
N = number of housing units.

children in the different housing categories, with the lowest amounts being found on children in public housing.

After data were deleted for children who moved, as described earlier, housing data for a total of 56 study participants were available for statistical analysis. The total of 333 blood lead values studied were distributed in the appropriate housing category as follows: I, 27%; II, 28%; III, 13%; and IV, 32%. The blood lead results are presented in Fig. 1 by age of child at time of blood sample collection and by housing type. Socioeconomic status did not differ for families among the housing quality categories and was uniformly low for all categories. Blood lead values differed significantly among children living in the various housing categories for ages 9–18 months, with those in public housing being lowest and those in the pre-World War II deteriorated/dilapidated housing being highest. Geometric mean blood lead for 12- to 18-month-old children in the deteriorated/dilapidated housing was two to three times higher than that for children in public housing. Average blood lead values for children in rehabilitated housing and in satisfactory pre-World War II housing were generally similar. By specifying housing quality categories, it was possible to account for 20, 32, 46, and 53% of the variability in the observed blood lead levels of 9-, 12-, 15-, and 18-month-old children, re-

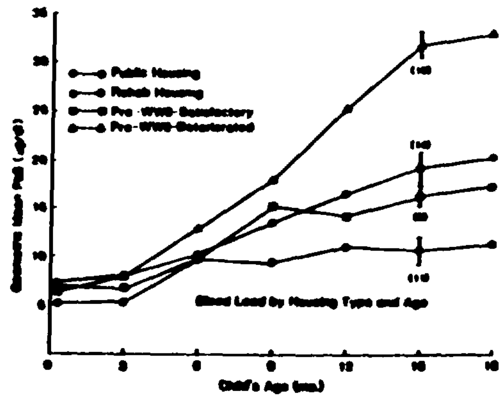

FIG. 1. Blood lead by housing type and age of child.

spectively. Although the overall differences in blood lead among the housing groups were not significant at 3 months of age, the blood leads of children in the poorer quality housing were significantly higher than in public housing (p = 0.04). Geometric mean blood lead levels at 3 months of age did not increase from those at 10 days. Thereafter, geometric mean blood lead values in general increased with age of child, with changes being greatest for children living in the poorer housing and least for those in public housing. The largest increase in blood lead between age groups occurred between 9 and 12 months in the poorer housing where the geometric mean increased from 17.7 to 26.2 μg/dl. Geometric mean blood lead values were relatively stable after 6 months of age for children in public housing, 9 months of age for children in pre-World War II satisfactory housing, and 15 months of age for children in rehabilitated and poor housing.

SUMMARY AND DISCUSSION

Paint and environmental dust lead levels were lower as expected in the public and subsidized rehabilitated housing than in the private housing. Hand lead levels, based on limited data, appeared to be about twice as high in the poorly maintained private housing than in public and rehabilitated housing and satisfactory private housing. Blood lead levels differed considerably among children classified by housing quality. Significant differences in blood lead associated with housing quality were detected in children as young as 9 months of age. The highest blood lead values were found in children living in pre-World War II housing in deteriorated or dilapidated condition, intermediate levels were detected in children in rehabilitated housing or other well-maintained older housing, and the lowest levels were found in children living in public housing and other recently built private housing. Although rehabilitated housing contained lower lead paint levels than did public housing, as determined by XRF, children in rehabilitated housing had higher blood lead levels than children in public housing, suggesting that lead sources in the immediate neighborhoods of the rehabilitated housing may be factors.

The locations of the housing in all four categories were in general the same with the only apparent differences being the clustering of public housing units, relatively more yard space of public housing units compared to the other housing categories, and the proximity to an interstate highway of much of the public housing. The larger amount of yard space for public housing may be responsible for the relatively low dustfall levels in public housing. Ambient air levels were probably similar for all four categories with the exception of possibly higher levels for much of the public housing because of their closer proximity to a heavily used interstate highway. In spite of this closeness to traffic, children in public housing had the lowest blood lead levels, suggesting that air lead from highways has only a very limited effect on blood lead in children in this study. Vacuum dust lead levels were lower for the public housing than for the other three housing categories on a concentration basis but were the same as in the rehabilitated housing on an area basis (mg/m^2). Interior dust fall levels for public housing were the same as in rehabilitated housing on a concentration basis. The persistence with age of the blood lead differences by housing category will be evaluated up to at least 5 years of age as the prospective study in which the children are participating continues. In addition, procedures will be developed to evaluate blood lead data from children who have moved between housing quality categories. Limited data currently available for children at 21 and 24 months of age revealed the same general trends as those exhibited at the younger ages.

In Cincinnati, the most effective intervention measure to reduce lead exposure appears to be to improve the quality of the housing stock by more efforts to create public and rehabilitated housing and to stimulate satisfactory maintenance of other older housing.

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